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14. ABSTRACT
This proposal examined how humans combine multiple sources of information when deciding to select a region of interest in a visual display. We considered tasks in which the observer was under time pressure to search a noisy display for a variable number of targets, or when the observer had to build an accurate representation of a new shape. We measured task performance as well as eye-scanning strategies as observers performed these tasks and compared these measures to the predictions of the optimal model. The model predicts that the most efficient strategy is to direct fixations to regions of maximum uncertainty, i.e. to regions that would maximize the information gained. Consistent with our model predictions, human eye movements in both tasks preferentially go to locations about which the observer is most uncertain. We also examined whether eye movements became more efficient when costs/penalties were involved. Performance improved slightly (5%) when observers were trained with a penalty for inefficient eye movements. A more effective way of improving performance was to guide humans to make eye movements to locations predicted by the optimal model. These results have implications for using the

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2. STATEMENT OF OBJECTIVES

Airport baggage screeners must quickly study a cluttered x-ray image for a large number of predetermined items. If they see an unidentifiable item, they must decide whether it requires further scrutiny. This is an extreme example of the kinds of visual tasks we encounter each day and perform effortlessly as we move our eyes to likely target locations or interesting features. How does our visual system combine information across space and determine which locations are useful for the task? In this proposal we investigate how humans combine multiple sources of information under conditions of information overload, time pressure and degradation in the periphery. We develop a model that computes uncertainty over space with respect to the task at hand, and predicts the sequence of regions an observer will select.

Aim 1: Find multiple targets in clutter

In this aim we compare human and model strategies when the task is to estimate the number and locations of independent targets in a noisy display.

a. Search for static targets while fixating: In this experiment, observers fixate a central marker as they search for multiple targets. They are asked to report the number of targets and to rate how confident they are that a target was present at a particular location. How does their criterion change as we manipulate the noise, probability of target occurrence or penalty for missing a target? Does the performance correlate with our model predictions?

b. Determine the location of targets with eye movements: We repeat the first experiment but now allow the observer to move his or her eyes while searching. We study the observers' selection decision by recording eye movements and comparing them to our model. Do observers select maximally uncertain regions as predicted?

c. Active search for dynamic targets: When we allow eye movements, we must integrate the new visual information that is being acquired. This update becomes even more challenging when the display is dynamic, with targets moving in straight paths amidst dynamic noise. Observers will be asked to report the number of targets and to locate them. Are several saccades planned initially, or do we continually incorporate new information? Does the future location of the target influence our decisions?

Aim 2: Learn a novel shape

This task is more challenging because local information is no longer independent over space, but is constrained by the context of the entire shape.

a. Search for targets along a closed contour: Observers are asked to report the number of target shape segments on a noisy circular profile that is equidistant from fixation. We parametrically alter noise amplitude to reduce target visibility and compare performance to Aim 1a. Does the lack of independent information affect performance?

b. Determine context-dependent resolution of orientation: Preliminary experiments show that the resolution of a small part of the contour is not determined simply by eccentricity. It depends critically on both the local smoothness of the surrounding contour and on the global shape of the figure. We quantify this effect and incorporate it into our model.

c. Predict the sequence of eye movements while learning a novel shape: We will modify our model to incorporate our findings about context-dependent resolution and the time required to update information from a saccade, and a cost for making large saccades. We will test our model predictions by comparing them with human eye movements during shape learning.

3. STATUS OF EFFORT

Our goal was to determine efficient ways to combine information from multiple sources. In **Aim 1** we conducted experiments to determine human performance when faced with the task of finding multiple targets under noisy conditions and time pressure. The displays were were too brief to inspect all locations visually so human observers had to choose carefully the locations they inspected. We measured task performance as well as eye-scanning strategies as observers performed these tasks. We then compared human performance and eye movements to the predictions of the optimal model for these tasks—a model that maximizes the information gained on each eye fixation. Our model predicts that the most efficient strategy is to direct fixations to regions of maximum uncertainty, i.e. to regions that would maximize the information gained.

Predictably, performance declined with increasing noise level. More interestingly, the locations that humans inspected changed as a function of signal-to-noise ratio (uncertainty). At low noise levels, observers did not move their eyes, as the signal was visible without eye movements. At higher noise levels, our data indicate that they moved they eyes first to the locations that could not be clearly distinguished as signal or as noise regions. This finding is consistent with our model, which predicts that the most efficient strategy is to direct fixations to regions of maximum uncertainty, i.e. to regions that would maximize the information gained.

In **Aim 2** we measured human ability to learn a novel shape under time pressure: We used novel silhouettes that were large and presented in the periphery, So the task required the operator to gather information from multiple parts of the contour. Furthermore, time pressure forced the observer to gather this information efficiently. For the simplified case of the silhouettes that we used, the stimulus information was simply the orientations along the contour of the shape. The most uncertain regions corresponded to parts of the stimulus that were distant from fixation, and that had multiple orientations within a neighborhood. We compared human eye movements to the predictions of three models: the information gain model described above, a random model where fixation locations were selected randomly, and a saliency model where fixations were made to the distinctive features that were easily discriminated from their surroundings. Our results showed that human eye movements in the shape learning tasks preferentially went to locations about which the observer was most uncertain.

We also examined whether eye movements became more efficient when costs/penalties were involved. Performance improved when observers were trained with a penalty for inefficient eye movements, but the magnitude of improvement was only about 5%. A more effective way of improving performance is to guide humans to make eye movements to locations predicted by the optimal model. These results have implications for using the model both for long-term training and for on-line assistance to the human operator.

4. ACCOMPLISHMENTS/NEW FINDINGS

We have three conclusions from our study

1. Eye movements are task dependent. When observers try to gather as much information as possible in a brief stimulus presentation, they do not look necessarily at the most salient points, as described by other studies,
2. Observers move their eyes to locations that reduce uncertainty about the stimulus. Thus, they appear to use efficient strategies, although their performance falls short of optimal.
3. We also show that task performance improves considerably when humans are guided to make eye movements to locations predicted by the optimal model. Therefore our study has implications of using the model both for long-term training and for on-line assistance to the human operator.

5. PERSONNEL SUPPORTED

Preeti Verghese, Principal Investigator
James Coughlan, Co-Investigator

6. PUBLICATIONS

1. Renninger LW, Coughlan JM, Verghese P, Malik J. (2005) An information maximization model of eye movements. *Advances in Neural Information Processing Systems* **17**: 1121-1128.
2. Baldassi S, Verghese P. (2005) Attention to locations and features: different top-down modulation of detector weights. *Journal of Vision* **5**(6): 556-70.
3. McKee SP, Verghese P, Farell B. (2005) Stereo sensitivity depends on stereo matching. *Journal of Vision*; 5(10): 783-92.
4. Petrov Y, Verghese P, McKee SP. (2006) Collinear facilitation is largely uncertainty reduction. *Journal of Vision*; 6(2): 170-8.
5. Verghese P, McKee SP. (2006) Motion grouping impairs speed discrimination. *Vision Research*; 46(8-9): 1540-6.
6. **Verghese P.** (2007). Cueing search in clutter. In: *Computational Vision in Neural and Machine Systems*, Harris L, Jenkin M (eds.), Cambridge University Press, pp. 149-166
7. Renninger LW, **Verghese P**, Coughlan JM. (2007) Where to look next: Eye movements reduce local uncertainty. *Journal of Vision: 7, 3 (6): 1-17.* http://www.journalofvision.org/7/3/6/
8. McKee SP, **Verghese P**, Ma-Wyatt AM, Petrov Y. (2007). The wallpaper illusion explained. *Journal of Vision: 7, 14 (10): 1-11.* http://www.journalofvision.org/7/14/10/
9. Burr, DC, Baldassi S, Morrone MC, **Verghese P** (2008) Pooling and segmenting motion signals. Vision Research (Epub ahead of print).
10. Freeman E, **Verghese P** (2008). Peeling plaids apart (submitted).

7. INTERACTIONS/TRANSITIONS

a. Presentation at meetings

Conference Presentations:

Verghese P, Freeman E. (2006). Segmentation counteracts masking. Vision Sciences Society, May 6-11 Sarasota, FL.

Renninger LW, Verghese, P. Coughlan JM (2006). Eye movements incorporate knowledge of part structure. Vision Sciences Society, May 6-11 Sarasota, FL.

Verghese P, Renninger LW, Coughlan JM (2006). Modeling eye movements in a learning task task. AFOSR Cognition Review, Dayton, OH.

Renninger LW & Verghese P. (2007). Orientation discrimination in the periphery depends on the context. Vision Sciences Society, May 11-16 Sarasota, FL.

Verghese, P. Coughlan JM (2007). Evolution of a motion trajectory over time. Vision Sciences Society, May 11-16 Sarasota, FL.

Verghese P, (2007). Saccades to a target on a textured background. Society for Neuroscience, Nov 3-6, San Diego, CA.

Renninger, L.W., Verghese, P. & Fletcher, D. (2007). Efficiency of eye movements in low vision patients. Optical Society of America, Fall Vision Meeting.

Renninger, L.W., Dang, L. Verghese, P. & Fletcher, D. (2008). Effect of central Scotoma on eye movement behavior. Vision Sciences Society.

Verghese P. (2008). A model of visual decision making under time pressure. Workshop on Eye Movement Monitoring. NASA Ames Research Center. Apr 24-25.

Verghese P. (2008). Searching for multiple targets under time pressure. Society for Neuroscience.

7b. Consultative and Advisory functions:

1. Organizing Committee, Second Annual conference on Visual Attention, Buenos Aires, Argentina, 2007.
2. NSF Cognition Review Panel, 2007.
3. Editorial Board, *Vision Research*.

7c. Transitions: None

8. New discoveries, inventions, patent disclosures: None

9. Honors/Awards:

Presidential Early Career Award for Scientists and Engineers, 2000.

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